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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 643

A STUDY OF FLYING-BOAT TAKE-OFF

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Bureau of Aeronautics, Navy Department

Washington
April 1938

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By Walter S. Diehl

SUMMARY

It is shown that the normal resistance curve for a flying boat may be approximated by two straight lines. The equations for take-off distance and time, derived from this approximation, are applied to a series of flying boats and the resulting factors are plotted in nondimensional form in a series of charts. Take-off performances from the charts are shown to be in good agreement with step-by-step integrations. Some applications of the charts to the solution of general design problems are included.

INTRODUCTION

The calculation of take-off run and time for a flying boat is not especially difficult but it is a tedious process. The usual method is to calculate thrust and total resistance curves against speed and take the difference as net accelerating force from which the instantaneous acceleration is known. The relations between velocity, acceleration, space, and time enable curves to be so drawn that the area enclosed between desired limits is proportional to distance or time. Details of the method are given in references 1 and 2.

Owing to the nature of these calculations most engineers avoid the drudgery of repeating the process any more than is absolutely necessary. Consequently, the general knowledge concerning the relative importance of the active variables is very limited, and it would probably remain so for an indefinite period were it not possible to obtain a satisfactory approximation that is available for a systematic study of flying-boat take-off. This note is concerned with the development of approximation formulas, their application to a systematic series of fictitious flying boats, and the conclusions that may be drawn from a study of these results.

APPROXIMATE EQUATIONS FOR TAKE-OFF RUN AND TIME

Typical curves of resistance and thrust, taken from figure 136 of reference 2, are given on figure 1. In general, the resistance curve may be approximated by two straight lines intersecting at hump speed, as shown by the broken lines on figure 1. The take-off may therefore be investigated in two stages: the first represented by the distance and time required to attain hump speed with a linear variation in thrust and resistance, and the second stage representing the distance and time to accelerate from hump speed to take-off, with a linear variation in accelerating force that differs from that acting during the first stage. It is a matter of convenience to reduce the forces to unit forces (by dividing by the gross weight) and the speed to a speed ratio (by dividing by take-off speed V_G). This gives the simplified force diagram shown on figure 2.

The linear variation of thrust with speed shown on figure 2 may be represented by the equation

$$\frac{T}{W} = \frac{T_0}{W} \left(1 - k_1 \frac{V}{V_G} \right) \quad (1)$$

where T is the thrust at any speed V .

T_0 , the static thrust

V_G , the take-off or get-away speed

W , the gross weight

k_1 , a constant determined by the relation

$$k_1 = (T_0 - T_F)/T_0$$

T_F , the thrust at $V = V_G$

Below hump speed the resistance increases linearly with speed, or

$$\frac{R_1}{W} = k_2 \left(\frac{V}{V_G} \right) \quad (2)$$

If $\frac{R_H}{W}$ is the resistance at the hump, then

$$k_2 = \frac{R_H}{W} \frac{1}{\left(\frac{V_H}{V_G}\right)} \quad (3)$$

where V_H is the speed at the hump.

The accelerating force in the first stage is

$$\frac{F_1}{W} = \frac{T_1}{W} - \frac{R_1}{W} = \frac{T_0}{W} - \left(k_1 \frac{T_0}{W} + k_2\right) \frac{V}{V_G} \quad (4)$$

This force produces an acceleration

$$a_1 = g \frac{F_1}{W} = g \left[\frac{T_0}{W} - \left(k_1 \frac{T_0}{W} + k_2\right) \frac{V}{V_G} \right] \quad (5)$$

The distance required to accelerate from $V = 0$ to $V = V_H$ is given by the integral

$$S = \int_0^{V_H} \frac{V dV}{a_1} \quad (6)$$

or by substitution of equation (5) for a_1

$$\frac{gS_1}{V_G^2} = \int_0^{\frac{V_H}{V_G}} \frac{\frac{V}{V_G} \frac{dV}{V_G}}{\frac{T_0}{W} - \left(k_1 \frac{T_0}{W} + k_2\right) \frac{V}{V_G}} \quad (7)$$

On integration this gives:

$$\frac{gS_1}{V_G^2} = \left[\frac{-\left(\frac{V_H}{V_G}\right)}{\left(k_1 \frac{T_0}{W} + k_2\right)} + \frac{\frac{T_0}{W}}{\left(k_1 \frac{T_0}{W} + k_2\right)^2} \log \left[\frac{\frac{T_0}{W}}{\frac{T_0}{W} - \left(k_1 \frac{T_0}{W} + k_2\right) \frac{V_H}{V_G}} \right] \right] \quad (8)$$

The time required to accelerate from $V = 0$ to $V = V_H$ is given by the integral

$$t_1 = \int_0^{V_H} \frac{dV}{a_1} \quad (9)$$

or by substitution of the value of a_1 from equation (5)

$$\frac{gt_1}{V_G} = \int_0^{V_H} \frac{\frac{dV}{V_G}}{\frac{T_0}{W} - \left(k_1 \frac{T_0}{W} + k_2\right) \frac{V}{V_G}} \quad (10)$$

from on integration this *expression* gives

$$\frac{gt_1}{V_G} = \frac{1}{\left(k_1 \frac{T_0}{W} + k_2\right)} \log \left[\frac{\frac{T_0}{W}}{\frac{T_0}{W} - \left(k_1 \frac{T_0}{W} + k_2\right) \frac{V_H}{V_G}} \right] \quad (11)$$

In the second stage, above the hump, the variation of thrust T_2/W will be given by equation (1). The resistance will be given by

$$\frac{R_2}{W} = \frac{R_0}{W} \left(1 - k_3 \frac{V}{V_G}\right) \quad (12)$$

where R_0/W is a fictitious zero-speed resistance obtained by extrapolation of the resistance curve back to zero speed. The value of R_0/W may be obtained directly from the hump resistance R_H/W and the final or take-off resistance R_F/W . From similar triangles

$$\frac{R_0}{W} = \frac{R_H}{W} + \left(\frac{R_H}{W} - \frac{R_F}{W}\right) \left(\frac{\frac{V_H}{V_G}}{1 - \frac{V_H}{V_G}}\right) \quad (13)$$

The constant k_3 is given by $k_3 = (R_0 - R_F)/R_0$.

The accelerating force F_2 in the second stage is

$$\frac{F_a}{W} = \frac{T_a}{W} - \frac{R_a}{W} = \left(\frac{T_o}{W} - \frac{R_o}{W} \right) - \left(k_1 \frac{T_o}{W} - k_3 \frac{R_o}{W} \right) \frac{V}{V_G} \quad (14)$$

and the corresponding acceleration is

$$a_2 = \frac{g F_a}{W} = g \left[\left(\frac{T_o}{W} - \frac{R_o}{W} \right) - \left(k_1 \frac{T_o}{W} - k_3 \frac{R_o}{W} \right) \frac{V}{V_G} \right] \quad (15)$$

The distance required to accelerate from hump speed to take-off speed is given by the integral

$$S_2 = \int_{V_H}^{V_G} \frac{V dV}{a_2} \quad (16)$$

or by substitution of the value of a_2 from equation (15)

$$\frac{g S_2}{V_G^2} = \int_{\frac{V_H}{V_G}}^1 \frac{\frac{V}{V_G} \frac{dV}{V_G}}{\left(\frac{T_o}{W} - \frac{R_o}{W} \right) - \left(k_1 \frac{T_o}{W} - k_3 \frac{R_o}{W} \right) \frac{V}{V_G}} \quad (17)$$

which gives

$$\frac{g S_2}{V_G^2} = \left[\frac{\left(1 - \frac{V_H}{V_G} \right)}{\left(k_1 \frac{T_o}{W} - k_3 \frac{T_o}{W} \right)} - \frac{\left(\frac{T_o}{W} - \frac{R_o}{W} \right)}{\left(k_1 \frac{T_o}{W} - k_3 \frac{R_o}{W} \right)^2} \log \left[\frac{\left(\frac{T_o}{W} - \frac{R_o}{W} \right) - \left(k_1 \frac{T_o}{W} - k_3 \frac{R_o}{W} \right)}{\left(\frac{T_o}{W} - \frac{R_o}{W} \right) - \left(k_1 \frac{T_o}{W} - k_3 \frac{R_o}{W} \right) \frac{V_H}{V_G}} \right] \right] \quad (18)$$

The time required to accelerate from hump speed to take-off speed is given by the integral

$$t_2 = \int_{V_H}^{V_G} \frac{dV}{a_2} \quad (19)$$

substitution of the values of a_2 from equation (15) and converting to ratio form gives

$$\frac{gt_2}{V_G} = \int_{\frac{V_H}{V_G}}^1 \frac{\left(\frac{dV}{V_G}\right)}{\left(\frac{T_0}{W} - \frac{R_0}{W}\right) - \left(k_1 \frac{T_0}{W} - k_3 \frac{R_0}{W}\right) \frac{V}{V_G}} \quad (20)$$

and on integration

$$\frac{gt_2}{V_G} = \frac{1}{\left(k_1 \frac{T_0}{W} - k_3 \frac{R_0}{W}\right)} \log \left[\frac{\left(\frac{T_0}{W} - \frac{R_0}{W}\right) - \left(k_1 \frac{T_0}{W} - k_3 \frac{R_0}{W}\right)}{\left(\frac{T_0}{W} - \frac{R_0}{W}\right) - \left(k_1 \frac{T_0}{W} - k_3 \frac{R_0}{W}\right) \frac{V_H}{V_G}} \right] \quad (21)$$

These equations are less formidable than their appearance would indicate, and they are readily applied to a systematic series as will be shown later. Equations (18) and (21) become indeterminate when the accelerating force is constant, and in this case it is necessary to use supplementary equations. When the accelerating force is constant, $S = \frac{V^2}{2a}$, hence

$$S_2 = \frac{V^2}{2a_2} = \frac{V^2}{2g \left(\frac{F_2}{W}\right)_{\text{const}}} \quad (22)$$

Introducing ratios and taking that part of S_2 between V_H/V_G and unity gives

$$\frac{gS_2}{V_G} = \frac{\left(1 - \frac{V_H}{V_G}\right)^2}{2 \left(\frac{F_2}{W}\right)_{\text{const}}} \quad (23)$$

In a similar manner, when the accelerating force is constant, $t = \frac{V}{a}$, hence

$$t_2 = \frac{V}{a_2} = \frac{V}{g \left(\frac{F_2}{W}\right)_{\text{const}}} \quad (24)$$

Introducing ratios and taking the time interval between V_H/V_G and unity gives

$$\frac{gt_2}{V_G} = \frac{1 - \left(\frac{V_H}{V_G}\right)}{\left(\frac{F_2}{W}\right)_{\text{const}}} \quad (25)$$

DEVELOPMENT OF TAKE-OFF CHARTS

Equations (8), (11), (18), and (21) have been applied to a systematic series in which a wide range of values were assigned to the basic variables (T_0/W) , (F_H/W) , and (F_F/W) . The results are given in condensed form for $V_H = 0.40 V_G$ in tables I and II. Similar values were obtained for $V_H = 0.33 V_G$ and $V_H = 0.50 V_G$ but these data are used only in the determination of correction factors for V_H , as will be indicated later.

The expressions (gS_1/V_G^2) appearing in equation (8) and (gt_1/V_G) appearing in equation (11) are nondimensional distance and time integrals, respectively. These may be plotted as functions of the specific static thrust (T_0/W) and the specific excess thrust or accelerating force at the hump (F_H/W) , as in figures 3 and 4, using the data from table I. In a similar manner, the distance and time integrals for the second stage (gS_2/V_G^2) and (gt_2/V_G) may be plotted as functions of the specific excess thrust at the hump (F_H/W) and the specific excess thrust at take-off (F_F/W) , as in figures 5 and 6, using the data from table II. As a matter of convenience, the normally used portions of figures 5 and 6 have been re-plotted to an enlarged scale in figures 7 and 8.

Figures 3 to 8 inclusive are based on $V_H = 0.40 V_G$. The correction factors for any other value of V_H have been determined and are plotted on figures 9 and 10.

The total distance run during take-off is $S = S_1 + S_2$ or, in general form,

$$\frac{gS}{V_G^2} = k_{s_1} \left(\frac{gS_1}{V_G^2}\right) + k_{s_2} \left(\frac{gS_2}{V_G^2}\right) \quad (26)$$

where k_{s_1} and k_{s_2} are the correction factors for actual hump-speed ratio given on figures 9 and 10.

The total time required for the take-off is $t = t_1 + t_2$ or, in general form,

$$\frac{gt}{V_G} = k_{t_1} \left(\frac{gt_1}{V_G} \right) + k_{t_2} \left(\frac{gt_2}{V_G} \right) \quad (27)$$

where k_{t_1} and k_{t_2} are the correction factors for actual hump-speed ratio given on figure 9.

It is of interest to note that the factors k_{t_1} and k_{t_2} are linear with the value of V_H . The factor k_{s_1} varies as the square of the hump-speed ratio, but the factor k_{s_2} obviously depends on the slope of the curve of accelerating force between the speeds V_H and V_G .

ACCURACY OF CHARTS IN TAKE-OFF ESTIMATION

Table III contains complete data used in applying the curves of figures 3 to 10 to the approximation of take-off distance and time for four flying boats for which step-by-step integrations were available. The maximum difference between the two methods is less than 3 percent, which is probably within the accuracy to which thrust and resistance are known. It therefore appears that the charts may be safely used in take-off estimates when the resistance curve can be represented by an approximation of the type shown on figure 1. This approximation is intended to give the same average accelerating force as the actual resistance curve in the second stage. This type of approximation is valid as long as the accelerating force does not approach zero over an appreciable portion of the high-speed range. When the latter condition exists with the actual distance greater than, say, 5,000 feet and take-off time longer than 60 seconds, the values will be found rather sensitive to slight changes in the final resistance. Investigation of several extreme cases has shown that the error involved in the use of the charts may run as high as 15 percent under conditions, however, that are of little practical interest.

PRACTICAL APPLICATION OF TAKE-OFF CHARTS

It has been shown that the curves of figures 3 to 10, inclusive, are sufficiently accurate for the average take-off estimate. Their greatest value, however, lies in the answer they provide to a number of questions regarding the effect of form of resistance curve on take-off characteristics. Among these questions may be listed the following:

- a) Proportion of the total distance and time required to reach hump speed.
- b) Comparative effects of a high and a low value of hump speed.
- c) Comparative effects of low accelerating force at hump speed and at take-off.
- d) Limits on accelerating force for specified take-off performance.

The answers to these questions serve to indicate the general hull characteristics required to meet different design conditions.

DISTANCE AND TIME TO ATTAIN HUMP SPEED

It is a matter of considerable interest, and occasionally of importance, to know what percentage of the take-off distance and time are required to attain hump speed. The ratios desired are simply S_1/S and t_1/t , and these may readily be obtained from the distance and time integrals in tables I and II. Figures 11 and 12 give S_1/S and t_1/t in terms of the accelerating force at take-off. The value of the static thrust has comparatively a small effect as indicated by the three curves on each figure. The value of the accelerating force at the hump likewise has a very small effect. The ratios are practically determined by the take-off accelerating force only. For an average flying boat the hump speed is attained after about 10 percent of the total run requiring approximately 20 percent of the total take-off time.

EFFECT OF LOCATION OF HUMP SPEED

It seems logical to expect that the relative value of the hump speed in terms of the get-away speed must have an appreciable effect on the take-off. If the hump speed is low, the wing lift will also be low and the water resistance will tend to be high. If the hump speed is high, the wings will be developing an appreciable lift and the water resistance will tend to be low. Since, in general, load can be carried more efficiently by the wings than by the dynamic action on the hull, it follows that there is some reason for favoring a high hump speed. However, this effect is not sufficiently great to be a determining factor. Its influence may be secondary to the slope of thrust against speed. If the thrust decreases with speed, a low hump speed means more thrust available for overcoming resistance and, conversely, a high hump speed means less thrust available. If the thrust increases with speed it appears that a high hump speed is decidedly preferable.

The general question of the effect of hump speed on take-off involves too many factors for a simple answer. It is possible, however, to obtain some indication of the type of variation to be expected. Values of the take-off integrals have been determined for a systematic series of values of static thrust T_0/W , accelerating force at the hump F_H/W , and final accelerating force at take-off F_F/W . The final accelerating force appears to be the most important variable, very little variation being obtained by changes in T_0/W and F_H/W . The curves of relative distance and time given on figures 13 and 14 for $\frac{T_0}{W} = 0.25$ and $\frac{F_H}{W} = 0.04$ are typical of the entire series. These indicate that under the assumed conditions the relative location of the hump speed is not highly important but that the general tendency is to show slightly more favorable results for high hump speeds.

SLOPE OF ACCELERATING FORCE AT PLANING SPEEDS

Some of the hull characteristics that tend to give low hump resistance, for example, a shallow step, may have an adverse effect on planing speeds. It is often possible by making such changes to alter the shape of the planing

resistance curve very materially, with a corresponding effect on the curve of accelerating force at planing speeds. The question is simply what type of accelerating force curve is most desirable. An approach to the answer to this question is obtained by comparing the take-off integrals for selected values of F_H/W , and F_F/W , first in a given order and then inverted. For example, using data from table II, when $\frac{F_H}{W} = 0.02$ and $\frac{F_F}{W} = 0.04$, the value of gS_2/V_G^2 is 13.84, and the value of gt_2/V_G is 20.79. If the accelerating force values are interchanged to $\frac{F_H}{W} = 0.04$ and $\frac{F_F}{W} = 0.02$, the value of gS_2/V_G^2 is 15.27, and the value of gt/V_G is 20.79. The time integral is unchanged because the average accelerating force remains constant, but the distance integral is always increased when the accelerating force at the hump is increased, at the expense of the accelerating force at take-off.

The comparison outlined above has been made for a series of force values and the results are given in figure 15, which indicates the desirability of securing low resistance at high speeds whenever take-off distance is a consideration.

ACCELERATING FORCE REQUIRED TO MEET

SPECIFIED PERFORMANCE

One of the normal requirements in flying-boat performance is that the take-off be accomplished in a specified time. Since the get-away speed is known, the required value of gt/V_G is known, and the values of the accelerating forces F_H and F_F may readily be determined by the use of the special plotting on figure 16. The contours on this figure are prepared by assuming a series of values of T_0/W and F_H/W , thus determining the value of gt_1/V_G . Thus, for any assumed value of gt/V_G , the value of gt_2/V_G is known and the value of F_F/W may be determined for the corresponding F_H/W on figure 8.

As shown by the dotted curves on figure 16, variation in static thrust has very little effect on accelerating forces required.

The use of figure 16 may be illustrated by a numerical example. If the take-off time is not to exceed 60 seconds, with a get-away speed of 120 feet per second, the time integral must not exceed

$$\frac{gt}{V_G} = \frac{32.2 \times 60}{120} = 16.1$$

This integral is satisfied by the following combinations:

F_H/W	0.01	0.02	0.04	0.047	0.08	0.16
F_F/W	0.166	0.106	0.055	0.047	0.022	0.004

An estimate of the probable value of F_F/W determines the corresponding required value of F_H/W . Since the thrust curve may be assumed as known, the maximum acceptance resistance is also known by differences.

CONCLUSIONS

The conclusions indicated by this study are as follows:

1. The resistance curve for a flying boat may, in general, be satisfactorily approximated by two straight lines.
2. A graphical solution of the equations based on the linear approximation gives satisfactory agreement with step-by-step integration.
3. The relative distance and time required to reach hump speed depend largely on the value of the accelerating force at high speeds; the effect of variation in static thrust is small and the effect of variation in accelerating force at the hump is negligible.
4. Neglecting any effects due to variation in thrust with speed, the effect of a reasonable variation in the actual hump speed is negligible except for very heavily loaded seaplanes.

5. Where take-off distance is a consideration, it may be advisable to accept a high hump resistance in order to obtain low planing resistance. The take-off time will depend only on the average accelerating force.
6. The take-off charts may be employed to determine the accelerating forces required to meet specified take-off performance.

Bureau of Aeronautics,
Navy Department,
Washington, D. C., January 15, 1938.

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TABLE I

Distance and Time Integrals between V_0 and V_H

$$V_H = 0.40 V_G$$

Static thrust	Excess thrust at hump	Distance integral	Time integral	Static thrust	Excess thrust at hump	Distance integral	Time integral
$\frac{T_0}{W}$	$\frac{F_H}{W}$	$\frac{gS_1}{V_G^2}$	$\frac{gt_1}{V_G}$	$\frac{T_0}{W}$	$\frac{F_H}{W}$	$\frac{gS_1}{V_G^2}$	$\frac{gt_1}{V_G}$
0.15	0.005	2.78	9.38	0.30	0.005	1.72	5.55
	.01	2.17	7.74		.01	1.39	4.69
	.02	1.63	6.20		.02	1.09	3.87
	.04	1.17	4.81		.04	.82	3.11
	.08	.79	3.59		.08	.58	2.40
0.20	0.005	2.28	7.57	0.40	0.005	1.39	4.44
	.01	1.81	6.31		.01	1.14	3.78
	.02	1.38	5.12		.02	.91	3.15
	.04	1.01	4.02		.04	.69	2.56
	.08	.70	3.05		.08	.51	2.01
0.25	0.005	1.95	6.39		.16	.35	1.53
	.01	1.57	5.36		.24	.28	1.28
	.02	1.21	4.39				
	.04	.90	3.49				
	.08	.64	2.68				
	.16	.43	1.98				
	.24	.33	1.63				

TABLE II

Distance and Time Integrals between Hump
and Get-Away Speeds

$$V_H = 0.40, V_G$$

Excess at hump	Thrust at get- away	Distance integral	Time integral	Excess at hump	Thrust at get- away	Distance integral	Time inte- gral
$\frac{F_H}{W}$	$\frac{F_F}{W}$	$\frac{gS_a}{V_G^2}$	$\frac{gt_a}{V_G}$	$\frac{F_H}{W}$	$\frac{F_F}{W}$	$\frac{gS_a}{V_G^2}$	$\frac{gt_a}{V_G}$
0.01	0.01	42.00	60.00	0.08	0.01	14.21	17.82
	.02	27.68	41.59		.02	10.64	13.86
	.04	17.55	27.73		.04	7.64	10.40
	.08	10.74	17.82		.08	5.25	7.50
	.16	6.39	11.09		.16	3.46	5.20
	.24	4.66	8.29		.24	2.66	4.12
0.02	0.01	30.54	41.59	0.16	0.01	9.13	11.09
	.02	21.00	30.00		.02	7.10	8.91
	.04	13.84	20.79		.04	5.32	6.93
	.08	8.77	13.86		.08	3.82	5.20
	.16	5.37	8.91		.16	2.62	3.75
	.24	3.97	6.78		.24	2.07	3.04
0.04	0.01	21.27	27.73	0.24	0.01	6.94	8.29
	.02	15.27	20.79		.02	5.51	6.78
	.04	10.50	15.00		.04	4.22	5.38
	.08	6.92	10.40		.08	3.11	4.12
	.16	4.39	6.93		.16	2.19	3.04
	.24	3.31	5.38		.24	1.75	2.50

TABLE III

Comparison of Take-Off Distance and Time Obtained by
Charts and by Step-by-Step Calculations

N.A.C.A. model No. Data from T.N. No.	11 464	11-A 486	22 488	26 512
W lb.	15000	15000	15000	34000
T_o lb.	4000	4200	4000	9800
T_H lb.	3700	3700	3800	8600
R_H lb.	3050	2600	2900	6000
$F_H = T_H - R_H$ lb. ✓	650	1100	900	2600
T_F lb.	3100	3050	3100	6400
R_F lb.	2150	2150	1500	4400
$F_F = T_F - R_F$ lb.	950	900	1600	2000
T_o/W	0.267	0.280	0.267	0.288
F_H/W	.043	.073	.060	.076
F_F/W	.063	.060	.106	.059
Hump speed V_H ft./sec.	37	37	27	43
Get-away speed V_G ft./sec.	106	106	106	124
V_H/V_G	.35	.35	.255	.346
(gS_1/V_G^2) for $V_H = 0.40 V_G$	0.85	0.65	0.74	0.64
k_{s_1} from figure 9	.77	.77	.40	.75
(gS_1/V_G^2)	.65	.50	.30	.48
(gS_2/V_G^2) for $V_H = 0.40 V_G$	7.80	6.40	5.15	6.40
k_{s_2} from figure 10	1.04	1.05	1.10	1.05
(gS_2/V_G^2)	8.11	6.72	5.66	6.72
gS/V_G^2	8.76	7.22	5.96	7.20
S from charts	3060	2520	2030	3440
S from calculation in reference	3120	2570	2090	3500
(gt_1/V_G) for $V_H = 0.40 V_G$	3.20	2.60	3.00	2.60
kt_1 from figure 9	.88	.88	.64	.87
(gt_1/V_G)	2.82	2.29	1.92	2.26
(gt_2/V_G) for $V_H = 0.40 V_G$	11.30	9.00	7.50	8.90
kt_2 from figure 9	1.08	1.08	1.24	1.09
(gt_2/V_G)	12.20	9.72	9.30	9.70
gt/V_G	15.02	12.01	11.22	11.96
t from charts	49.3	39.4	37.0	46.00
t by calculation in reference	50.0	39.6	36.8	46.00

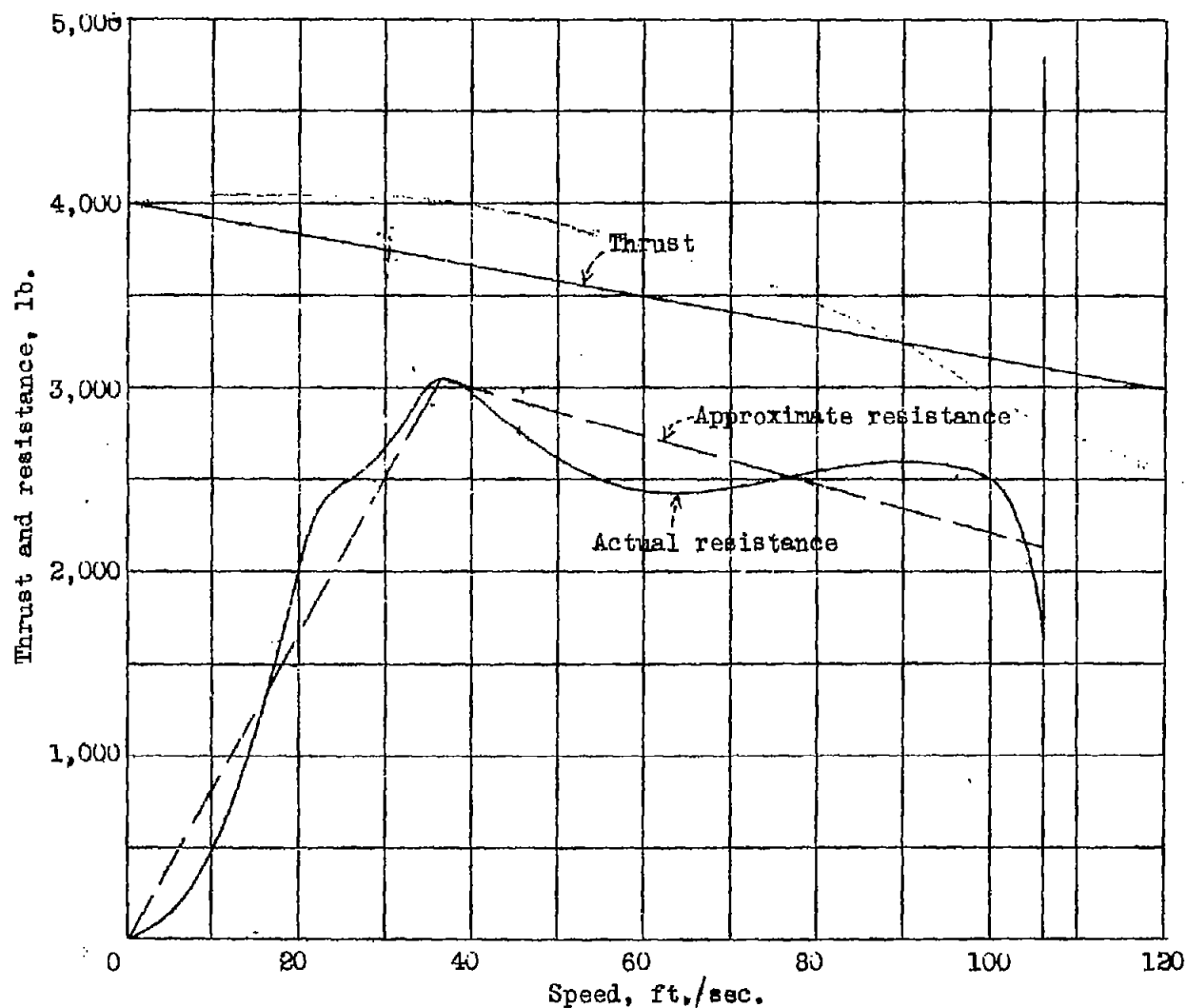


Figure 1.- Thrust and resistance in take-off. N.A.C.A. model 11 flying boat hull.

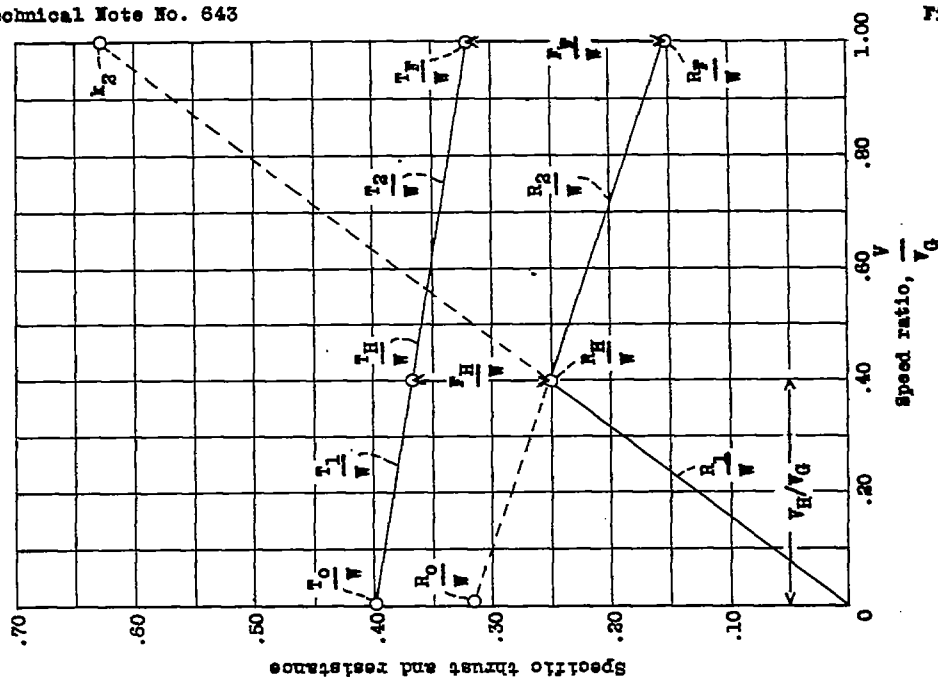


Fig. 2,3

Figure 2. - Approximation of thrust and resistance in take-off.

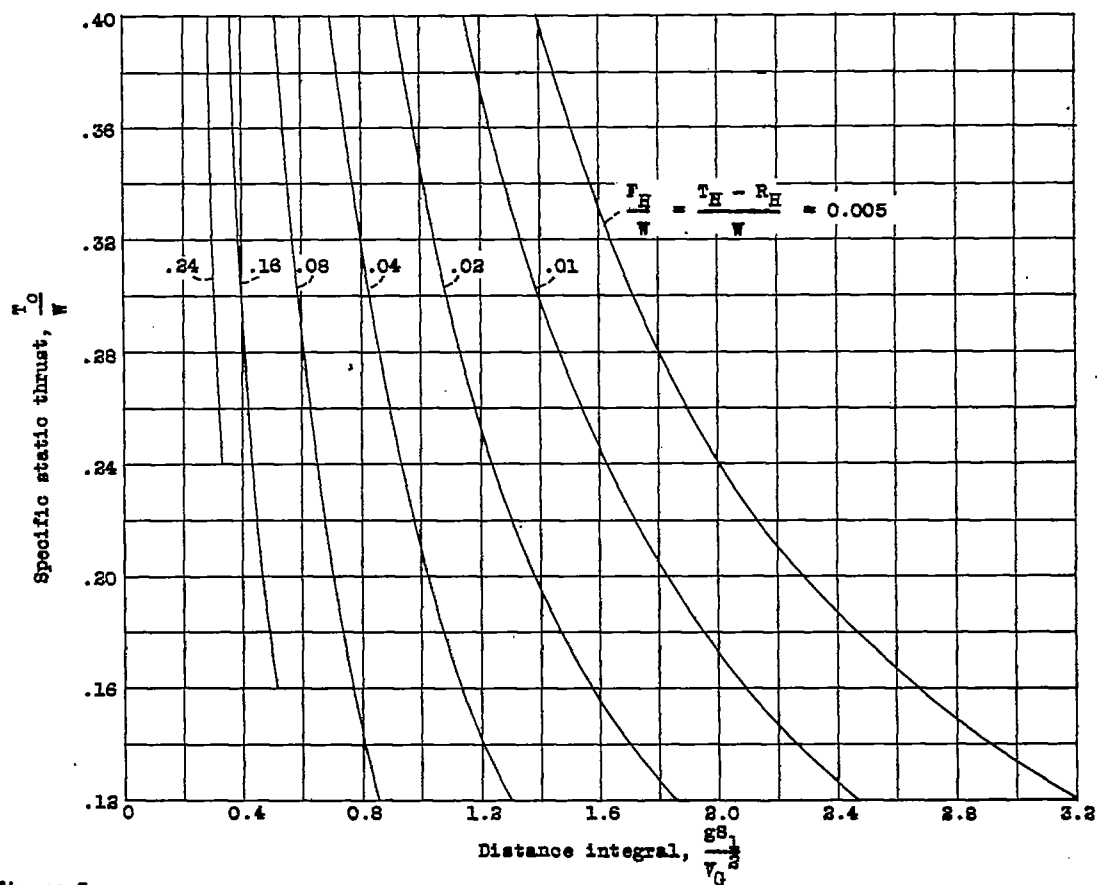


Figure 3. - Distance integral for first stage from start to hump speed. $V_H = 0.40 V_G$. Parameter = Specific excess thrust at hump speed.

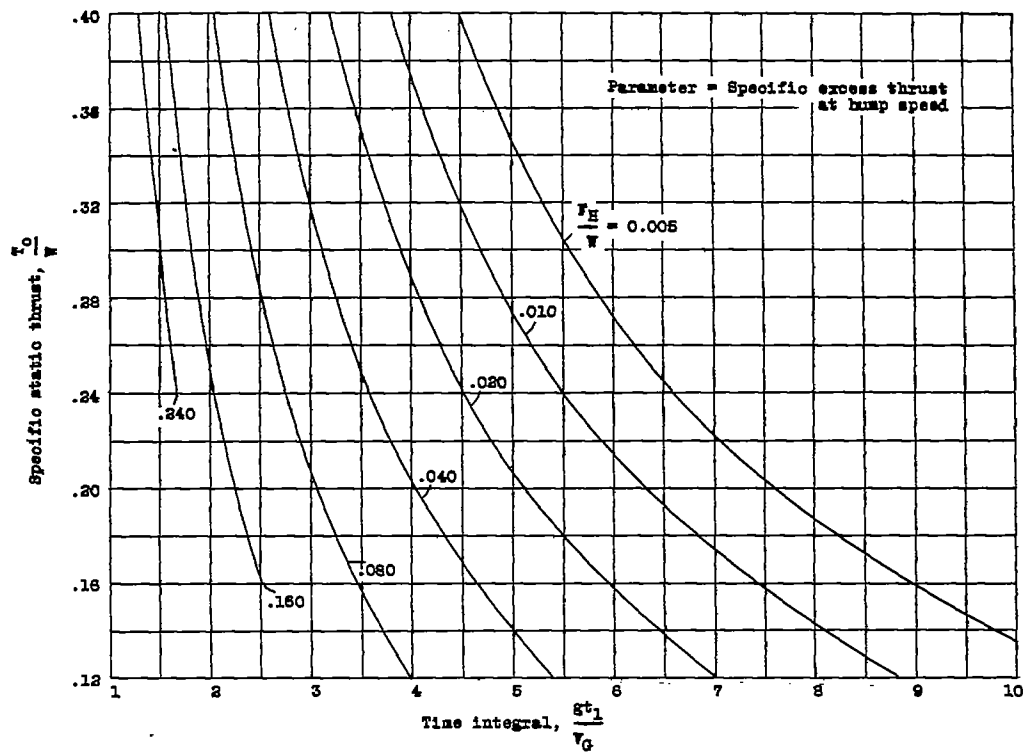


Figure 4. - Time integral for first stage from start to hump speed. $V_H = 0.40 V_G$

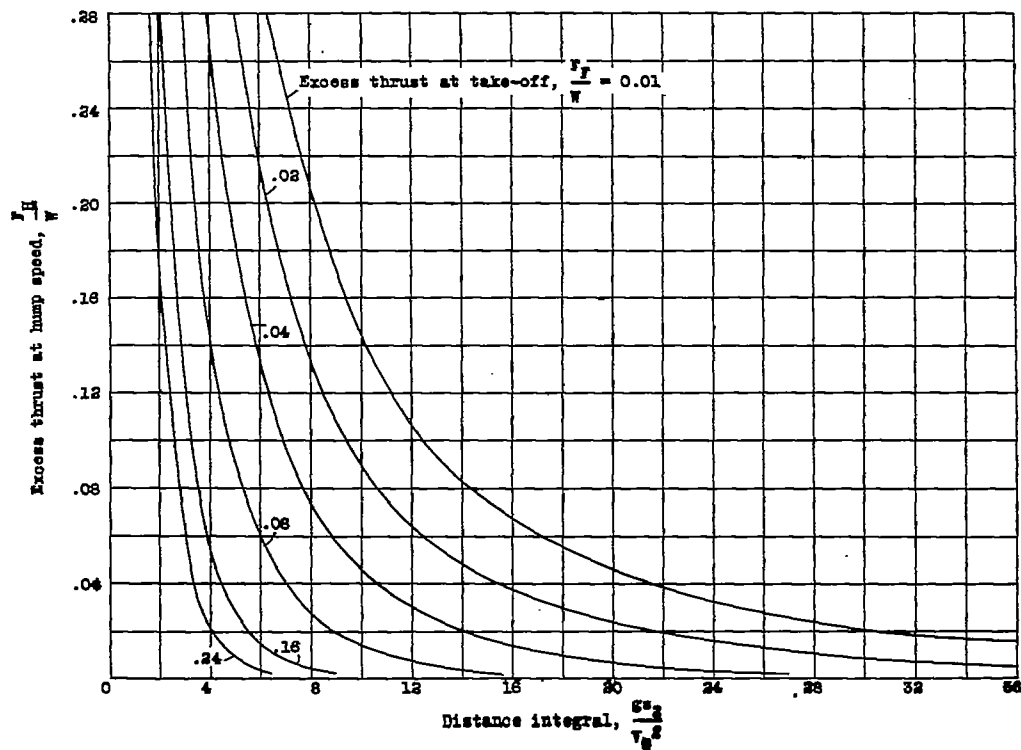


Figure 5. - Distance integral for second stage at hump speed to take-off. $V_H = 0.40 V_G$

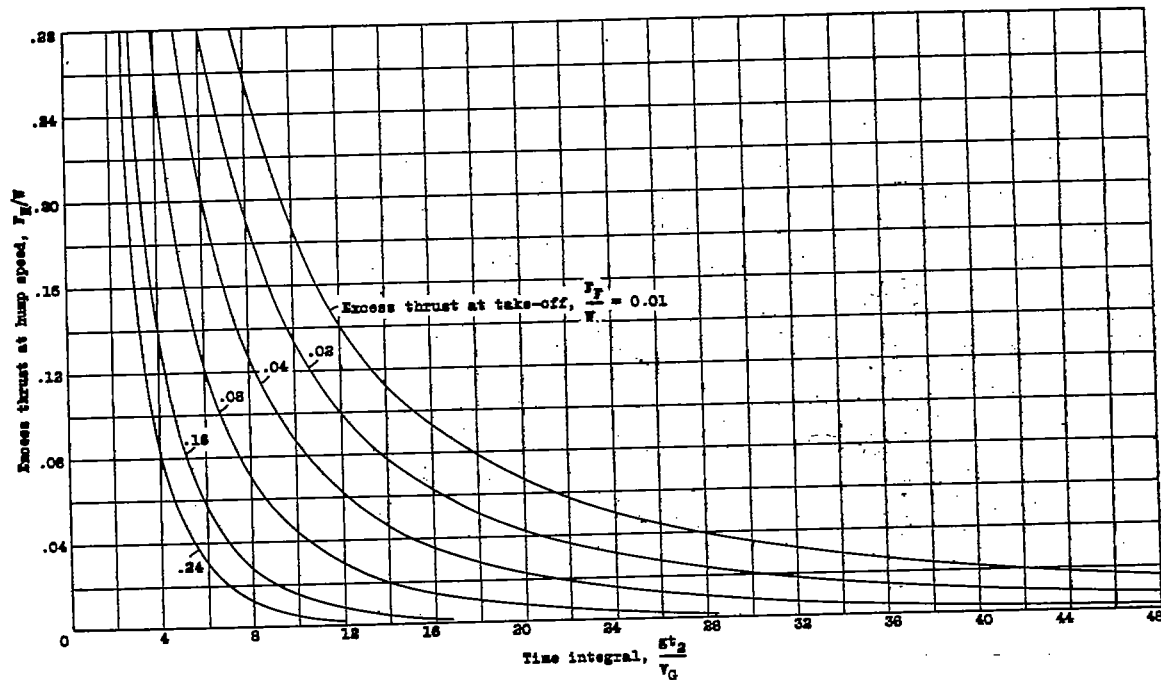


Figure 6. - Time integral for second stage at hump speed to take-off. $V_H = 0.40 V_G$

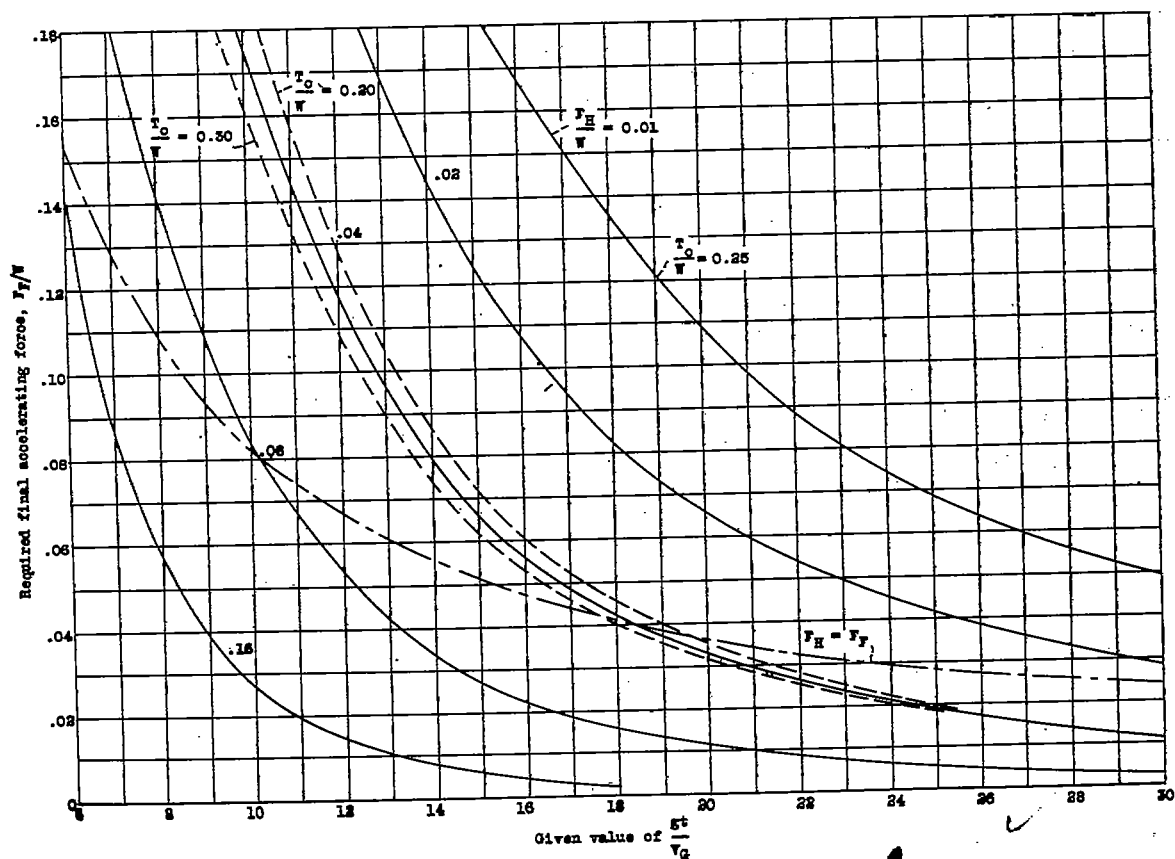


Figure 15. - Accelerating force required for given value of time integral

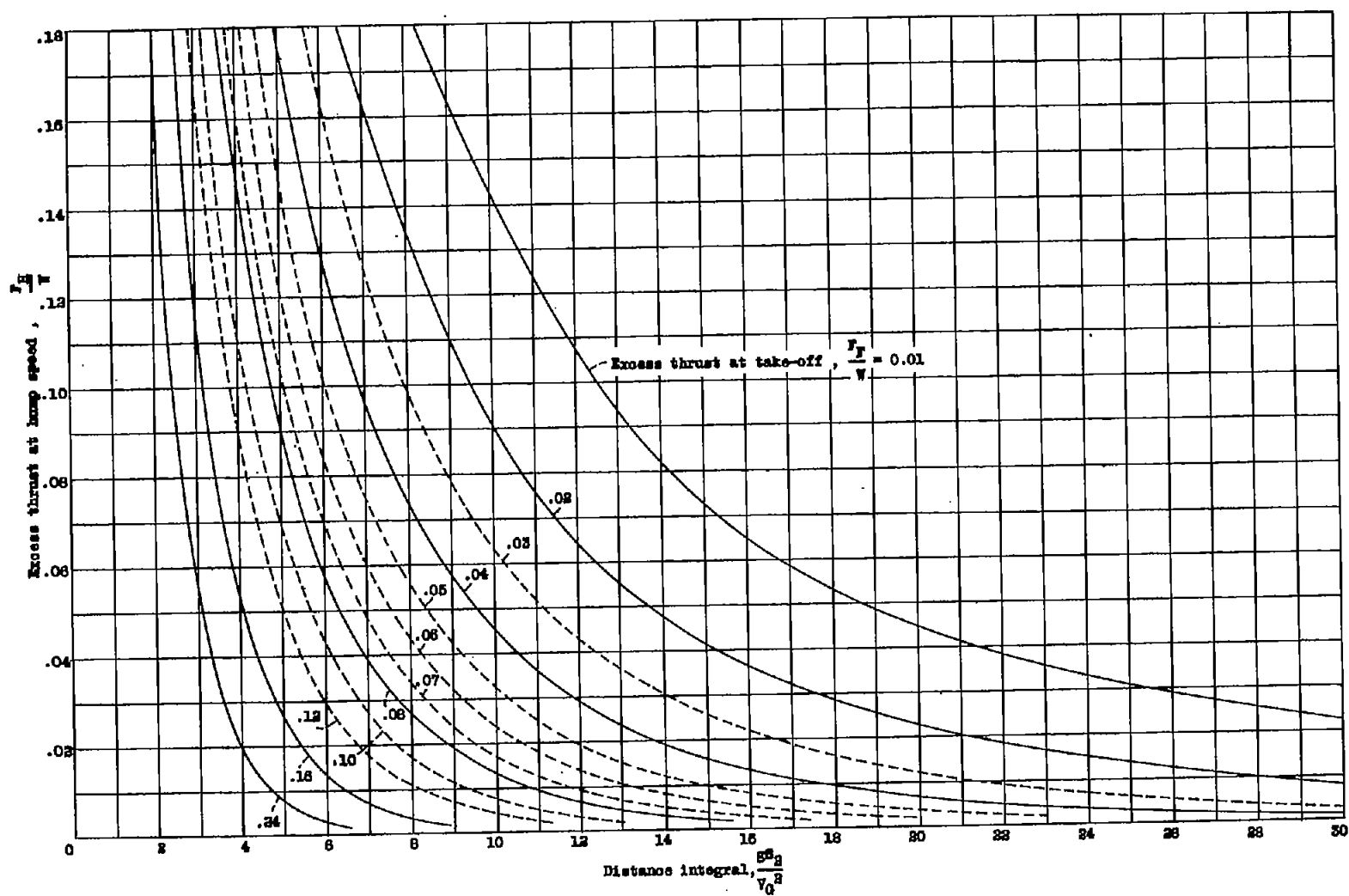


Figure 7. - Distance integral for second stage at hump speed to take-off. $V_H = 0.40 V_0$

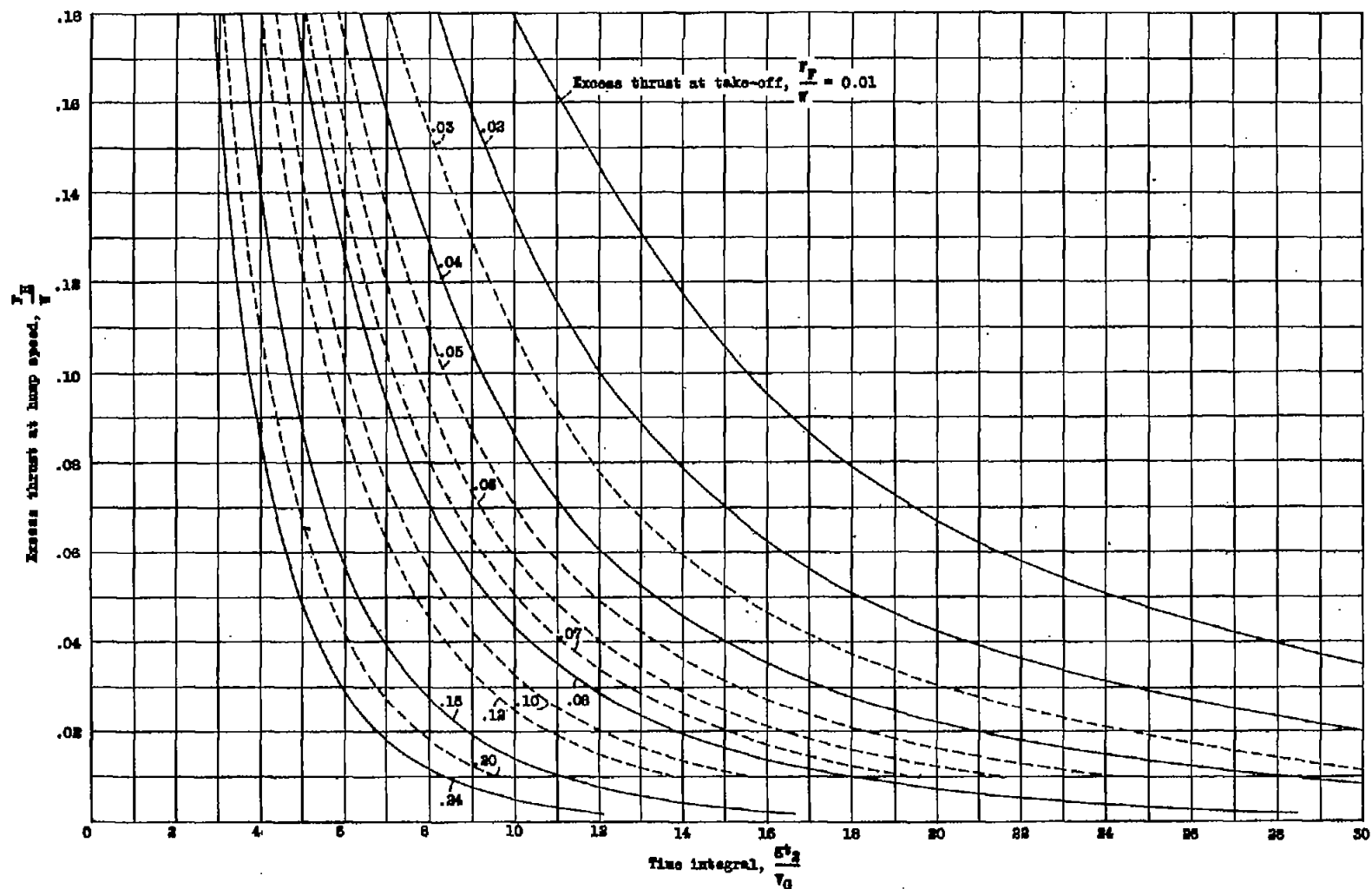


Figure 8. - Time integral for second stage at bump speed to take-off. $V_H = 0.40 V_0$

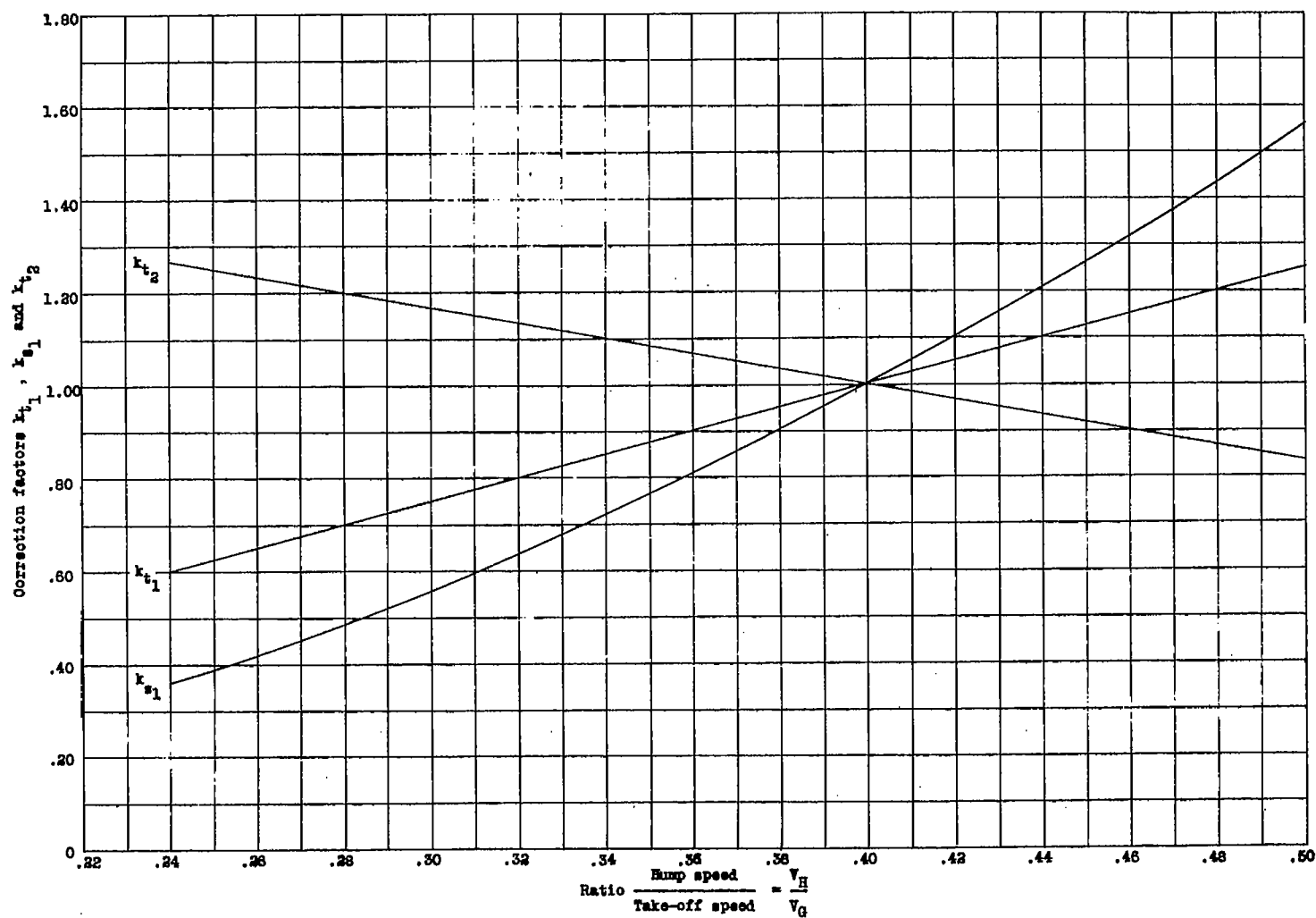


Figure 9. - Correction factors for effect of hump speed on distance and time integrals.

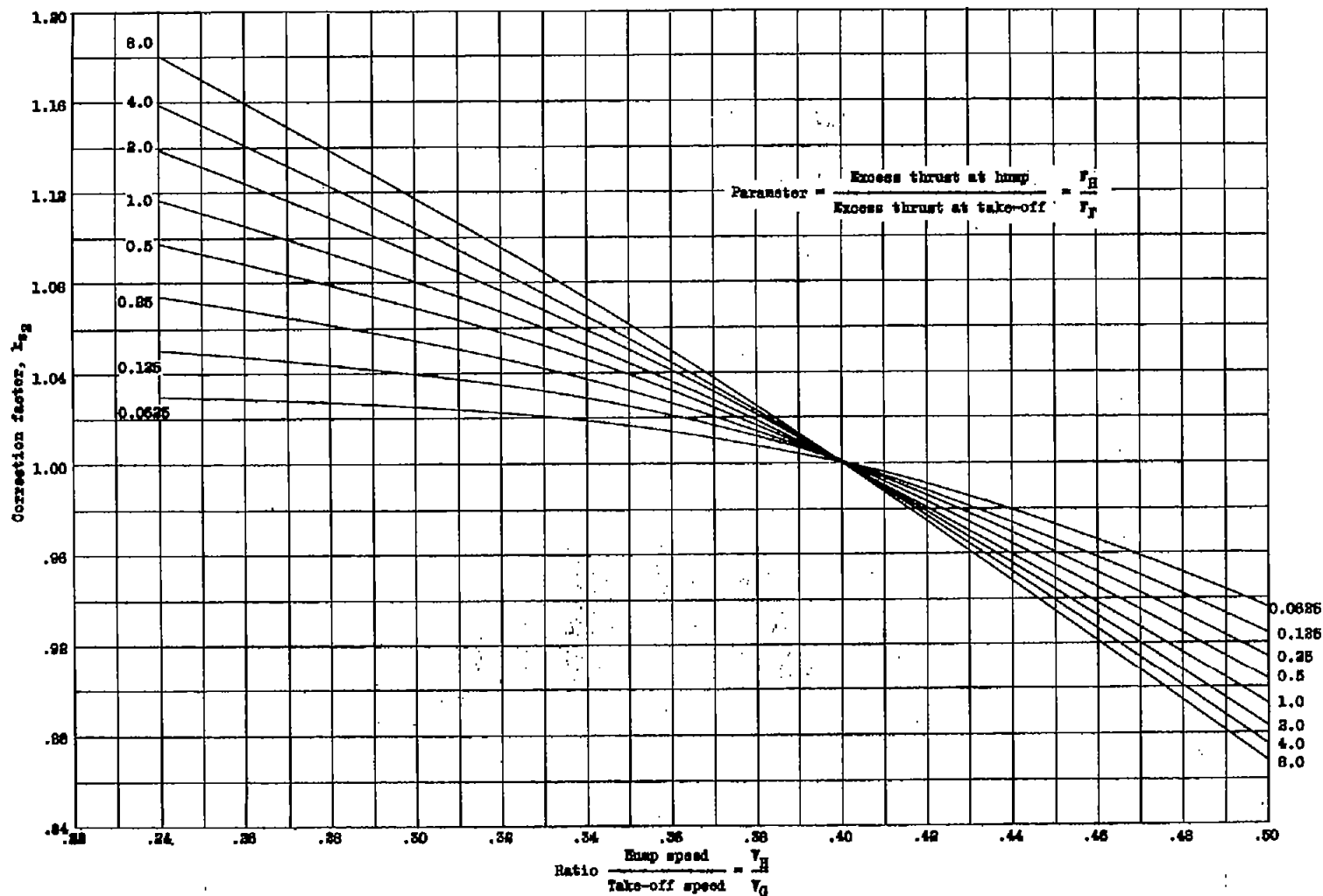
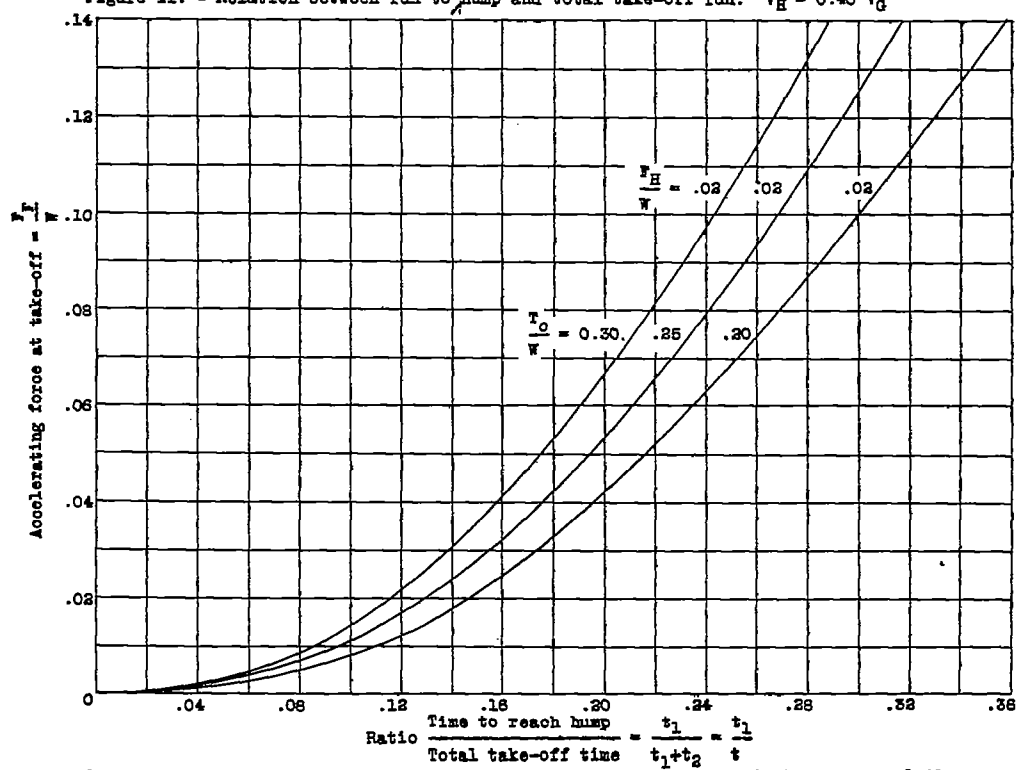
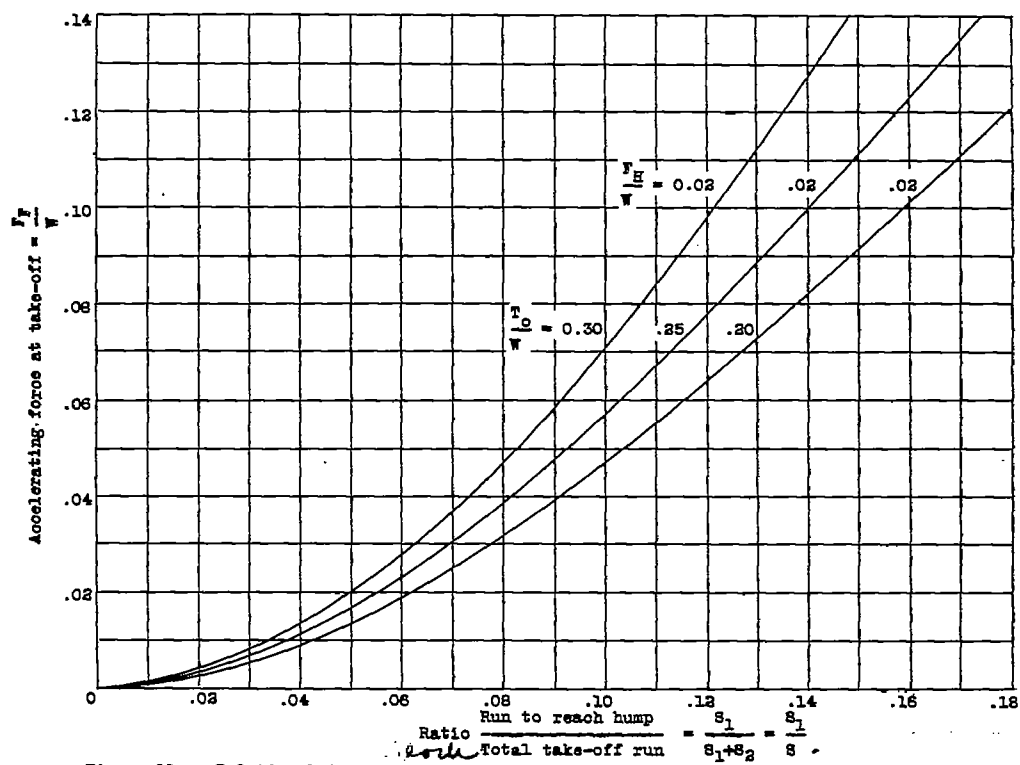
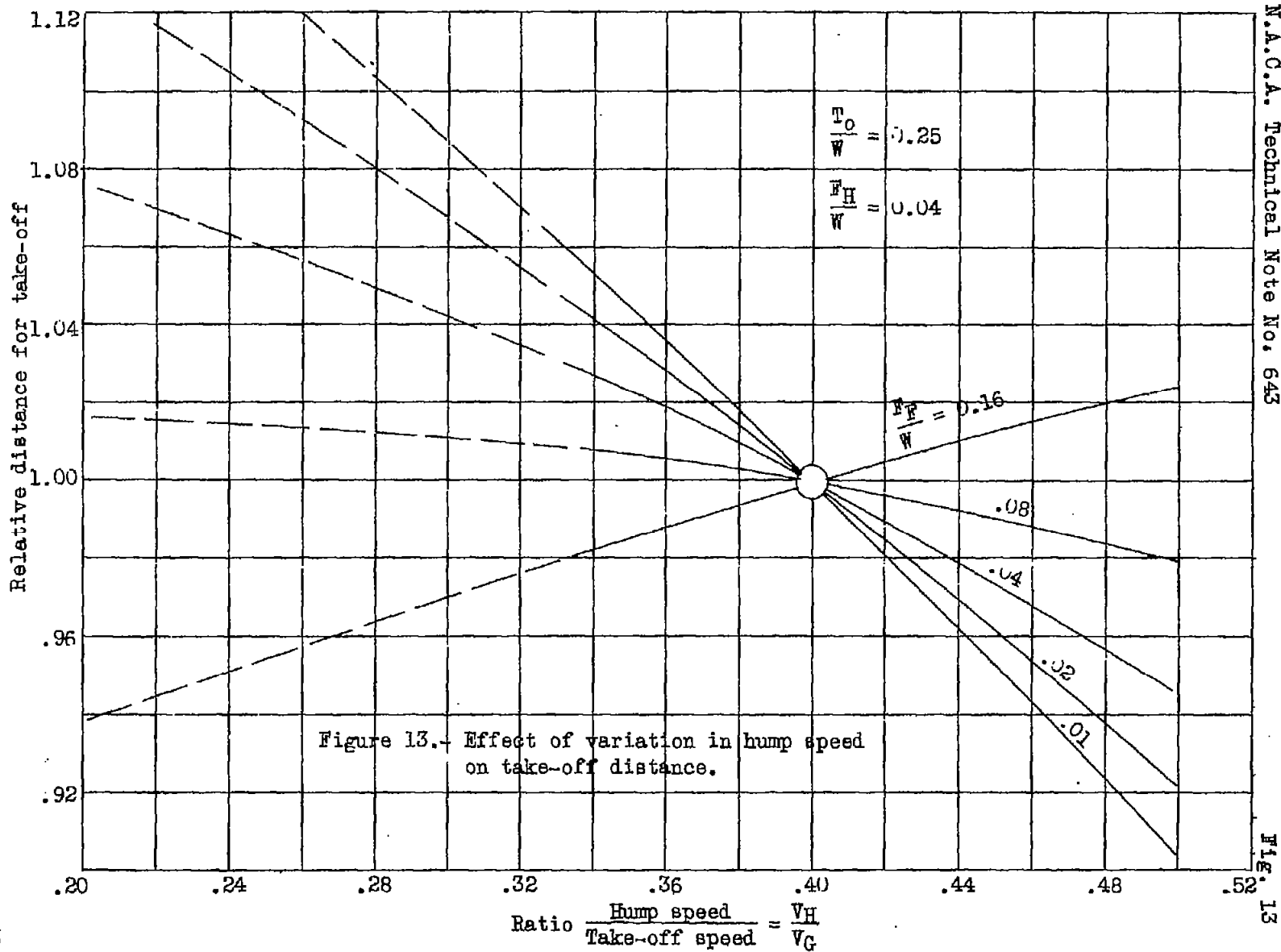


Figure 10. - Correction factor for effect of hump speed on distance integral in second stage.





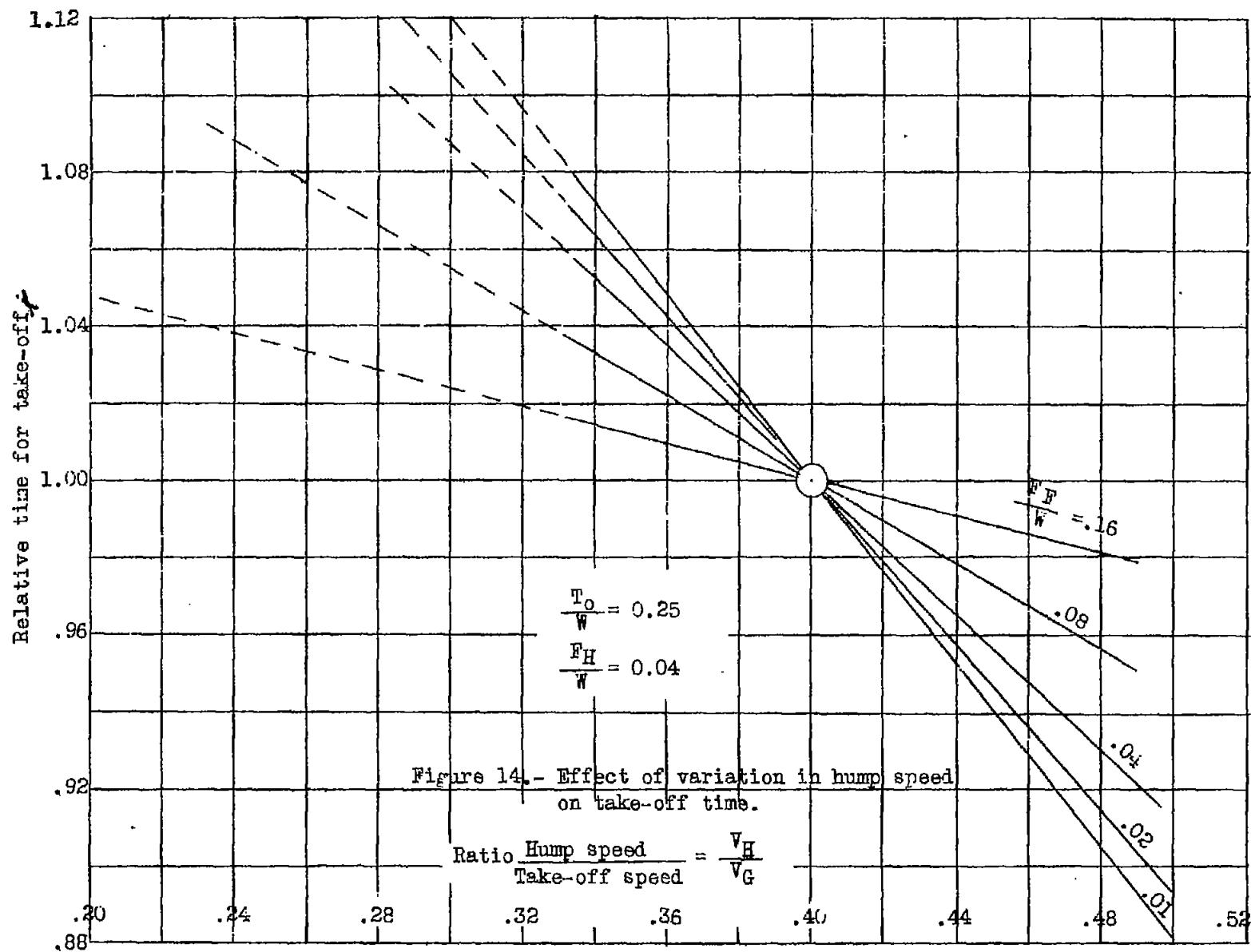


FIG. 14

